THE FLIGHT OF HAWKER AND GRIEVE.

On May 18, 1919, at 5.45 p. m., G. M. T., Mr. Harry G. Hawker and Commander Mackenzie-Grieve left St. John's, N. F., for a nonstop flight direct to Ireland. For several days no news of them was heard, but on May 25 the world was electrified to learn that these daring aviators had been rescued at sea by a Danish steamship. Mr. Hawker told his story simply as follows: [1]

"We had very difficult ground to rise from on the other side. To get in the air at all we had to run diagonally across the course. Once we got away we climbed very well, but about 10 minutes up we passed from firm, clear weather into fog.

"Off the Newfoundland banks we got well over this fog, however, and of course at once lost sight of the sea. The sky was quite clear for the first four hours, when the visibility became very bad. Heavy cloud banks were encountered, and eventually we flew into a heavy storm, with rain squalls.

"At this time we were flying well above the clouds at a height of about 15,000 feet.

"About five and one-half hours out, owing to the choking of the filter the temperature of the water cooling out the engines started to rise, but after coming down several thousand feet we overcame this difficulty.

"Everything went well for a few hours, when once again the circulation system became choked and the temperature of the water rose to the boiling point. We of course realized that until the pipe was cleared we could not rise much higher without using a lot of motor power.

"When we were about 10½ hours on our way the circulation system was still giving trouble, and we realized we could not go on using up our motor power.

"Then it was we reached the fateful decision to play for safety. We changed our course and began to fly diagonally across the main shipping route for about two and a half hours, when, to our great relief, we sighted the Danish steamer, which proved to be the tramp *Mary*.

"We at once sent up our Very light distress signals. These were answered promptly, and then we flew on about two miles and landed in the water ahead of the steamer.

"The sea was exceedingly rough and despite the utmost efforts of the Danish crew it was one and one-half hours before they succeeded in taking us off. It was only at a great risk to themselves, in fact, that they eventually succeeded in launching a small boat, owing to the heavy gale from the northeast which was raging.

"Altogether, before being picked up, we had been 14½ hours out from Newfoundland. We were picked up at 8:30 (British summer time)."

Commander Mackenzie Grieve, the navigator of the Sopwith, said:

"When but a few hundred miles out a strong northerly gale drove us steadily out of our course. It was not always possible, owing to the pressure of the dense masses of cloud, to take our bearings, and I calculate that at the time we determined to cut across the shipping route we were about 200 miles off our course.

"Up to this change of direction we had covered about 1,000 miles of our journey to the Irish coast. [The landing was made in latitude 50° 21′ N., and longitude 29° 30′ W.]"

During much of the time a straight course could not be steered because of clouds. In this way much time was lost, so it is not surprising that a speed of only about 80 miles an hour (1,050 statute miles in 13 hours) was, on the average, maintained. Very likely, however, this loss in speed was due in no small measure to the fact that cross winds prevailed during the greater portion of the flight. The air speed of the Sopwith machine is not known, but it was probably about 90 miles an hour, and the course of flight was on the average E. 15° N. If we assume that the wind blew approximately at right angles to the course with a speed of 40 miles per hour (and this is a fair assumption, judging from reports published [1]) we find that the machine, in order to follow the desired course, would have to make an angle with it of about 26½°, and the resultant speed would be only 81 miles per hour. Under the conditions of speed above given, i. e., wind 40 miles per hour and airplane 90 miles per hour, what might be called the wind's *critical* angle, or an angle with the course such that neither assistance nor resistance would be offered, is about 78°.[2]

A discussion of Alcock's and Brown's successful nonstop trans-Atlantic flight will appear in the June, 1919, number of the MONTHLY WEATHER REVIEW.—*W. R. Gregg.*

[1] New York Times, May 27, 1919, by courtesy of the London Daily Mail.

[1] See also Charts XV and XVI in this number of the Review.
[2] Cf. MONTHLY WEATHER REVIEW, February, 1919, p. 70.

A NEW EVAPORIMETER FOR USE IN FOREST STUDIES.

By C. G. BATES.

[Dated: U. S. Forest Service, Denver, Colo., April, 1919.]

SYNOPSIS.—This article treats of the subject of evaporation or transpiration from plants, of the factors which influence it, and of the conditions which must be met before water losses from plants can be approximately determined through instrumental evaporation.

It is pointed out that the "evaporation stress" or tendency to evaporate, is produced by a different combination of factors in each body from which evaporation may occur. Because of the fact that the vaporizing process in leaves takes place on the surface of moist cell walls which are not directly exposed to the moving air, the theory would lead us to expect that the effect of wind would be greatly minimized in evaporation from leaves, the rate of diffusion of the vapor being almost completely controlled by vapor pressures in the leaf (inter-cellular) spaces. On the other hand, the leaf is admirably adapted for absorbing the sun rays of all wave lengths; hence evaporation from leaves will be more directly controlled by the supply of radiant energy than perhaps will that from a body which does not absorb so readily and which may obtain considerable heat from the air, especially if a strong wind brings new supplies of air rapidly to the evaporating surface.

The article then describes the efforts which were made to devise an instrument having about the same relation to wind and to radiant energy as do leaves of plants in general. The idea of an "inner cell" for the vaporizing process, rather than a freely exposed moist surface, was the basis for these efforts. The result was a very practical metallic instrument known as the "Type 4 evaporimeter," whose behavior and operation are fully described. The essential feature of this instrument is a moist layer of linen between two metal plates, the upper of which protects the wick from rain, is coated with lampblack and transmits absorbed heat to the wick; the lower plate is thick and contains a number of small perforations simulating the stomata of leaves. Vapor formed in the moist linen escapes through these perforations. The layer of linen is above a well-insulated tank, from which it is fed by a stem wick. Distilled water is used and evaporation losses are obtained by weighing before and after exposure.

It is shown that considering either a large number of daily periods having a variety of weather conditions, or shorter periods at different times of the day, the evaporation from the Type 4 evaporimeter parallels the total transpiration of 12 small coniferous trees more closely than does the evaporation from other instruments commonly used in ecological study, or the earlier types which led up to Type 4. "The others show wider variation (from the plants) about in proportion to the degree in which they expose the evaporating surface to moving air, and fail to absorb fully the heat of sunlight."

This parallelism between plants and the new instrument comprises the sole technical argument in favor of its use, at the same time demonstrating the correctness of the theory on which the instrument was constructed.

On the other hand, the new instrument has an apparently objectionable feature in exposing a horizontal surface to evaporation. This, it is shown, may possibly be an advantage, if, as it appears, plant activity becomes less as the season advances, and the instrument at the same time exposes its absorbing surface less squarely to the sun's rays.

In the closing paragraphs the practical features of the instrument are stressed, and precautions in its use are given.

INTRODUCTION.

The purpose of the present paper is to describe the construction, behavior, and operation of a new evaporimeter or atmometer which has been designed particularly for studies in forest ecology, but which may find a wider field of usefulness. Before attempting such description it will be well to outline some of the theoretical and practical considerations which have led to the development of this instrument.

Perhaps the only respect in which forest studies demand a different treatment from other ecological studies, is in the year-long observations, necessitated by the perennial nature of the plants involved. Because of this there seemed to be demanded an evaporimeter which could be used under any weather conditions. Results already secured, and soon to be published(1), fully justify the assumption that winter records of evaporation are necessary for an understanding of forest problems.

PURPOSE OF EVAPORATION MEASUREMENTS.

It is presumed that there is a common object in most measurements of evaporation, whether made for purely climatological purposes, or in connection with ecological or physiological studies of plants or animals, namely, to secure an integration of the effects of all those factors which contribute to evaporation, any or all of which might be independently measured more precisely and almost as readily as evaporation itself, but which vary in their combined action to such an extent that no formula has ever satisfactorily integrated them even with relation to evaporation from bodies of free water.

As the present writer understands the matter, evaporation with respect to animals is of greater importance in effecting sensible temperatures than in effecting direct water-loss; with respect to soils, there is no constant evaporation problem in agriculture, because soil evaporation can be very largely controlled by cultivation, and in forestry there is likewise no constant soils problem, because the forest soil may be well or poorly protected by a mulch. The big, outstanding problem, susceptible of instrumental treatment, therefore, for ecologists, and for climatologists whether they will it or not, is the problem of the water-loss from plants to the atmosphere, and it is only with this problem that we propose to deal. Nothing will be gained by trying to combine this problem with that of evaporation from reservoirs, soils, etc.

Even this problem is not so simple as it would at first seem, for it is realized that no two plants, no two leaves of the same plant, will respond to evaporation stimuli in exactly the same way. Atmometry, at the best, must be only an approximate method for determining the reaction of the plant in the matter of transpirational water-loss. What it really aims to do is to integrate all of the factors which contribute to evaporation as nearly as possible in the same way that the plant integrates these factors. It is obvious that the goal can always be only approached, never reached, but this is no reason for failure to progress. It is almost absurd, for example, to measure evaporation for biological purposes in terms of a free-water surface, which is much more strongly influenced by wind movement, and less directly affected by solar radiation, than the plant.

Hereafter we shall speak of the total integrated value of the factors which contribute to evaporation as the "evaporation stress." This is not alone the product of atmospheric factors, for it includes as well the temperature of the body evaporating, as influenced by the supply of solar heat. It is therefore evident that the evaporation stress, for a given set of conditions, may be as variable as the kinds of bodies from which evaporation occurs. It is simply a convenient name for any integration. It seems to be necessitated by the fact that instrumental evaporation should be analyzed, that there should be a common basis for comparing evaporation with transpiration, and there should be a basis for determining whether a plant is evaporating in proportion to the stress existing, or possibly is holding up transpiration by some protective device.

THE COMPONENTS OF EVAPORATION.

The object here is simply to treat the factors which contribute to evaporation qualitatively, and not to devise a formula, but to make certain that no important item is overlooked.

The *maintenance* of a given rate of evaporation is dependent primarily upon the heat available for vaporization, while the rate of diffusion of the vapor from the evaporating body really controls the evaporation rate when other factors are constant.

In the case of the plant, heat is derived from radiation, direct or reflected sunlight being of the greatest importance; and from the air in contact with the plant.

In the case of the plant, again, the rate of diffusion of the vapor may be considered as a function of the differential vapor pressure between the intercellular spaces of the leaf and the atmosphere immediately surrounding the mouths of the stomata. The former may be considered for all practical purposes as the pressure of saturated vapor at the temperature of the leaf; the latter will be essentially the vapor pressure of the atmosphere, though slightly modified by the possible accumulation of vapor about the mouth of the stomata, and the aid to diffusion furnished by air movement or wind. There is some reason for supposing that the function of wind in aiding diffusion has been greatly exaggerated; that its primary effect on evaporation arises from the supplying of heat. There can be little doubt but that vapor molecules, when they become mixed with the molecules of the moving air, are set in motion in the prevailing direction, in spite of the molecular independence of the two kinds of gases. Both theory and experience, however, point to the hypothesis that when air is moving horizontally over a water surface it must aid materially in carrying the vapor molecules out of the zone from which they might readily return to the water mass; but when blowing over the surface of a leaf the air encounters only molecules which are measurably removed from the water mass, already moving away from it in the normal process of diffusion, and not likely to be diverted from that course. Of the molecules likely to enter the stomata the wind would, theoretically, not remove any more than it brought into range. At the best, then, wind movement simply aids to clear congestion around the stomata, and has no effect on the initial direction or velocities of the molecules as they are set free from the moist walls of the internal cells.

Heat required for evaporation.—By all odds the most important question in evaporation is the source and amount of the heat available for it; for, if heat is not supplied to the evaporating body, its temperature must quickly fall below that of the air and evaporation will approach the zero rate as the temperature of the body approaches that of the dew point.

The amount of heat required to evaporate a gram of water at the boiling point is about 537 calories, but the amount is greater at lower temperatures, and for ordinary purposes we may consider it as being 600 calories. The amount required to evaporate from an aqueous solution, such as the cell sap of the plant, is even greater, probably in most plants about 700 calories per gram.

As has been stated, most of this heat must be derived from direct solar radiation. The leaf is eminently adapted to absorb nearly all of the energy of the sunlight which falls upon it. The red and infra-red or "dark" rays, which possess a large part of the heat energy, are readily absorbed by the water and cell walls of the leaf. Some of the visible light escapes. The ultra-voilet portion of the spectrum may be considerably absorbed by the chloroplasts, but we shall consider that this energy is all used in photosynthesis. Of the total energy of sunlight about 2 calories per square centimeter per minute at outer limits of atmosphere, there should be available for evaporation or heating, after making all allowances, possibly 1 calorie. To evaporate at the rate of 1 gram of water per hour, requiring say 700 calories, the leaf would therefore only have to expose about 12 square centimeters normally to the sun's rays.

If the same amount of heat were to be supplied by conduction from the air, it would be necessary that 2 cubic meters of air should come in contact with the leaf every hour, assuming that the air were only 1° C. warmer than the leaf. And, assuming that in passing over the leaf a layer of air 1 mm. thick might transmit all its surplus heat to the leaf, there would be required a velocity of between 30 and 40 miles per hour to bring this volume of air within effective distance of the leaf. This calculation simply serves to accentuate the importance of sunlight as a source of heat for transpiration and to show how impotent the only other possible source would ordinarily be.

Conversely to the previous proposition, if the conditions in the leaf were such, and the humidity of the atmosphere were so high, that evaporation did not occur readily, the temperature of the leaf might be higher than that of the air, and air movement would tend to carry away heat from the leaf, to just the same extent that it has been shown to be a possible source of heat. Under such circumstances the effect of wind in helping to diffuse vapor, we have reason to believe, is just about neutralized, and wind may, therefore, when the vapor pressure within the leaf is barely higher than that of the outer atmosphere, be non-effective in producing evaporation.

There is another relation of heat to evaporation which I have never seen discussed. The velocities of vapor molecules, and the resultant rates at which they will diffuse from the intercellular spaces to the outside air, do not increase as rapidly as their temperatures. At the same time, other conditions remaining the same, a higher leaf temperature must mean a larger supply of heat, and a greater number of vapor molecules set free each moment. In the inter-cellular spaces of the leaf, with a rising temperature, due to steadily increasing insolation, we therefore have this condition: The number of molecules set free from the liquid increases, the repulsion between the molecules also increases, each requiring more space; there is set up within the leaf an accumulated vapor pressure, causing a discharge in excess of the normal rate of diffusion for the current temperature; equilibrium with the outside vapor pressure can only be maintained by a rate of diffusion somewhat greater than the rate of vaporization. When the heat supply and temperature are declining there will be reversal of this process—to store vapor. The result is simply this: That the rate of transpiration is higher when the temperature of the leaf is rising, than with the temperature declining, external vapor pressures, etc., being equal. It would not appear that the storage space in the leaf was sufficient to make this an important item. Yet such a conception seems necessary to account in part for higher transpiration rates, generally, in the morning than in the afternoon, for equal temperatures, vapor pressures, etc.

It is fairly obvious that this condition may not be duplicated in the layer adjacent to a free-water evaporating surface, because there is here no tendency for vapor to accumulate on account of inadequate avenues for escape. The phenomenon in the leaf is dependent upon the agency of the inner cell which stands between the evaporating surface and the outer air, and it therefore becomes apparent that an atmometer, if it is to follow the ups and downs of transpiration, must, like the leaf, have some space for the storage of vapor.

CONSIDERATIONS LEADING TO DEVISING OF NEW INSTRUMENT.

The matters which have just been mentioned appear to be purely theoretical, and they are that. They represent an attempt to place observed phenomena within the confines of some generally applicable hypothesis.

For the most part the phenomena which led up to this statement of the theory of evaporation and transpiration came to the writer's attention, in the form of Burns's work on the "Tolerance of New England Forest Trees," (**2**) just at the moment when he was struggling with the practical features of evaporation measurements. The observation regarding the relation of transpiration to differential vapor pressures is based on a long series of measurements by the writer, in 1917. These are soon to be published.

Among the points enumerated by Burns in his "Conclusions," and fully corroborated by his data, are the following, which seem to have a bearing on the present problem. The parenthetical elaborations are mine:

"2. When all of the factors affecting evaporation and transpiration agree (that is, all tend toward an increase or a decrease simultaneously) the black and white atmometers and plants agree (that is, increase or decrease together)."

"3. When certain factors are very marked (that is, when one or more are strongly predominant over others which might influence adversely) both instruments and plants agree.

"4. When the factors vary, some plus and some minus, the responses of the instruments and plants disagree, because both black and white atmometers and plants are affected differently by different factors.

"8. Plants normally reach the maximum water loss in the morning. If, however, the meteorological conditions are decidedly more favorable to water losses in the afternoon, the maximum loss may occur later in the day. (On normal days, in the above sense, when sunshine is essentially the same morning and afternoon, and the afternoon temperatures are higher, the relative humidity lower, with consequent higher deficit, the transpiration is markedly less in the afternoon than in the morning, while evaporation is usually somewhat greater).

"10. The effect of half-shade upon the plants is more marked than upon the instruments (in reducing losses).

"11. Evaporation-transpiration coefficients based on unit of dry weight of plants for no-shade, half-shade, and full-shade beds show that the response of the plant agrees more closely with the black atmometer than the white atmometer."

For present purposes these conclusions might be summed up as follows: The plants (tree seedlings) in their transpiration show greater dependence upon light than do the atmometers; the plants and black atmometer agree more closely than the plants and white atmometer because the black atmometer absorbs the more light of the two; because neither atmometer absorbs radiant energy as fully as the plants, or uses it so effectively to supply heat for vaporization, both show greater dependence for evaporation upon the temperature, humidity, and movement of the air than do the plants.

These technical considerations led to the decision to construct an atmometer which would be as sensitive as possible to sunlight effects, through complete absorption of the rays, and which should at the same time be less subject to the influence of the moving air, by exposing the evaporating surface within a chamber which should have only a small opening to the outer atmosphere. Thus, the desire to attain certain physical relations led to a mechanical construction somewhat similar to that of the leaf and gave rise to the name "inner-cell evaporimeter."

The practical consideration which led to the same end were mainly those brought out by the attempt to use existing atmometers for winter measurements. The Piche instrument had been very extensively used both winter and summer; in the winter by filling with an alcohol solution which could only be compared in evaporating rate with water, and not with ice; during the summer with the innumerable difficulties of overflowing in damp weather, and drying out or exhausting its water-supply in warm weather, under the necessary program of daily observations and adjustments. The Livingston porous cup had been tested in more expert hands and had demonstrated its utility and sensitiveness under growing season conditions, but with the first appearance of frost ceased to be serviceable. This technical feature of the porous cup and other objections to the then existing precise atmometers have been so fully explained by Livingston, (3) that it does not seem worth while to dwell upon their merits and demerits here. There is one additional point about the Livingston cup, however, which promised to be very troublesome in forest studies, where it is not always feasible to furnish protection against hail and other injury by the elements, or against squirrels, deer and other animals that will nose about. This is the fragile nature of the Shive non-absorbing apparatus, which must be used to obtain good results.

DEVELOPMENT.

The first effort to devise a more practical instrument for our field conditions, and for situations where infrequent visits were the rule, was made in the fall of 1915. This instrument did not possess any new physical features, but attempted to make use of the capillary properties of cotton wicking to overcome the feeding difficulties of the Piche instrument. In the top of a metal tank, which presented a flat surface designed always to be horizontal, two slits were made about 5 centimeters long and 5 centimeters apart, such that the ends of a strip of 2-inch wicking could be thrust through them, reaching down into the water in the tank. When drawn taut, there would be exposed on the top of the tank an evaporating surface of about 25 square centimeters. The tanks were designed to hold over a liter of water. They were provided with drain cocks, and the plan was to fill the tank at each observation with the contents of a liter-flask; after a period of evaporating, the water would be drawn off into the flask, and a graduate used to again fill the flask to capacity, thus obtaining a measure of the amount lost in the evaporating period. This method was, of course, slow, very difficult to carry out in freezing weather, and subject to the errors of all volumetric determinations under varying temperature conditions. The tanks, moreover, to withstand the pressure of ice had been made so heavy as to make close weighing in the field impracticable. The cotton wicking had abundant capillary capacity so long as it remained moist; drying out in freezing weather, however, it usually failed to remoisten itself. The comparisons between a shaded instrument and one fully exposed to the sun, were, moreover, very disappointing, and failed to bring out one of the secondary objects of the measurements, which was to obtain a measure of sunlight heating values. Not infrequently the insolated wick evaporated, in a strong wind, less than the shaded one. This could be interpreted as evidence that slight superheating of the wick above air temperature tended to eliminate air conduction as a source of energy for evaporation. It is possible that the shading device tended somewhat to increase the air current over the shaded wick. Even granting this, however, it becomes evident that the comparison of shaded and insolated, or black and white atmometers, can not possibly give a measure of sunlight intensities.

While these tests were being made, the theory of plant evaporation was becoming clarified and another plan was devised. The Type-1 instruments had at least shown that evaporation could be measured in below-freezing weather and that its amount was not inconsiderable.

The Type 2 wick evaporimeter, figure 1, embodied the idea of the "inner cell," corresponding in a rough mechanical way to the intercellular spaces of the leaf which the vapor of transpiration must first enter, or, we may say, in which the vaporizing process really occurs, almost free from outside air influences. The tank was of the same size as in Type 1, namely, 5 inches in diameter, and of about a liter capacity, heavily constructed, and with drain cock. On this was built a lighter superstructure of the same diameter, 3 inches high, and over this a low conical cover was laid, having a flange which fitted closely on the superstructure and was held to it by set-screws. At the peak of the cone a circular opening was made with a diameter of about 3.5 cms., or an area of almost exactly 10 sq. cms., for the admission of sunlight. In the "shade" instrument there was the same opening, but it was surmounted by a secondary conical cover 1 cm. above the first, and slightly more extensive than the opening.

Within the superstructure was a cylinder 3 inches in diameter, its open top terminating at the same level as the main walls; its lower end terminating in a wide-mouth funnel which opened just above the water level in the tank, or at the water level with the tank filled. On the inside of this cylinder was placed a cylindrical,

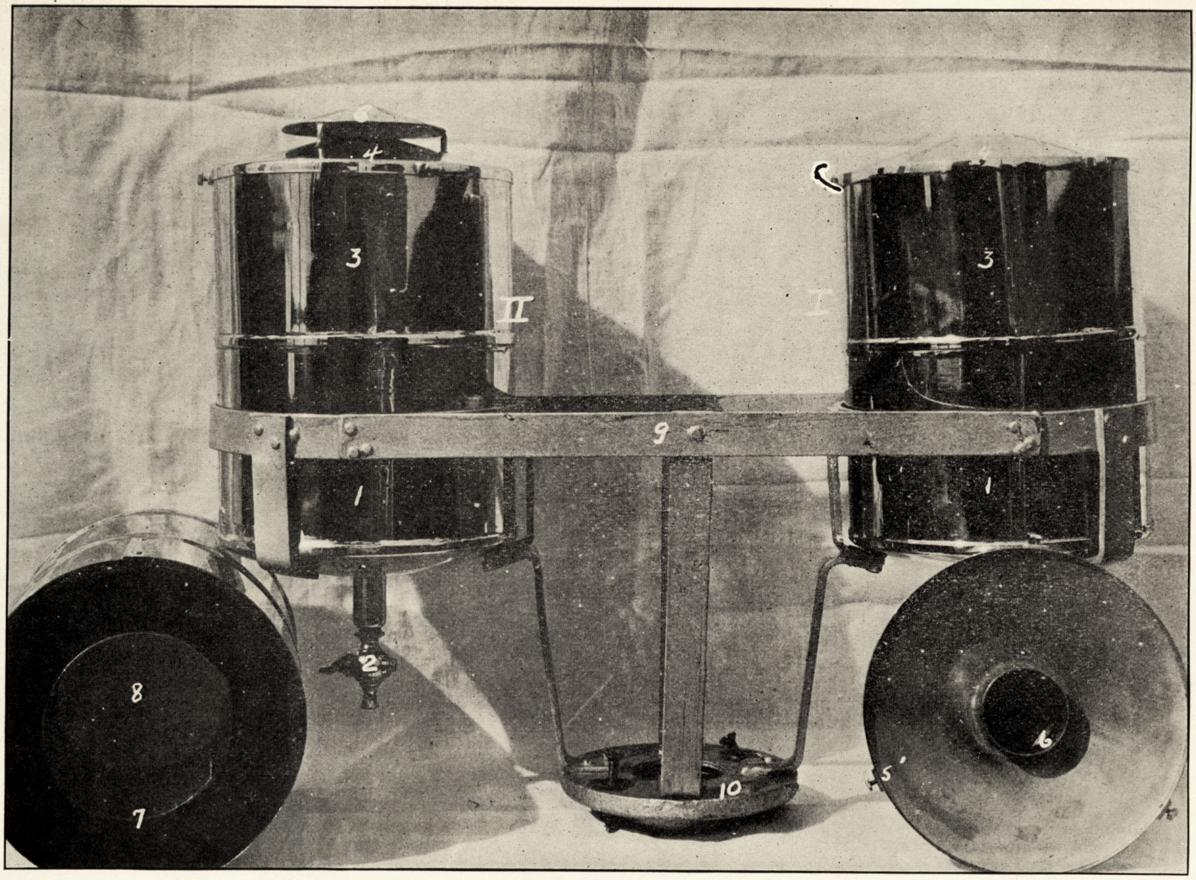

FIG. 1.—Type 2 Inner-cell Evaporimeter. I "Sun" and II "Shade" instrument, in appropriate basket for their support. (1) Tank, (2) Draincock, (3) Superstructure, (4) Cover, (5) Set screw to hold cover, (6) Opening for light and ventilation, and hood to shade opening on "shade" instrument, (7) Inner cylinder, (8) Funnel through which wick reaches into tank, (9) Basket, (10) Flange by which basket is secured to end of pipe or fastened to plank set in ground.

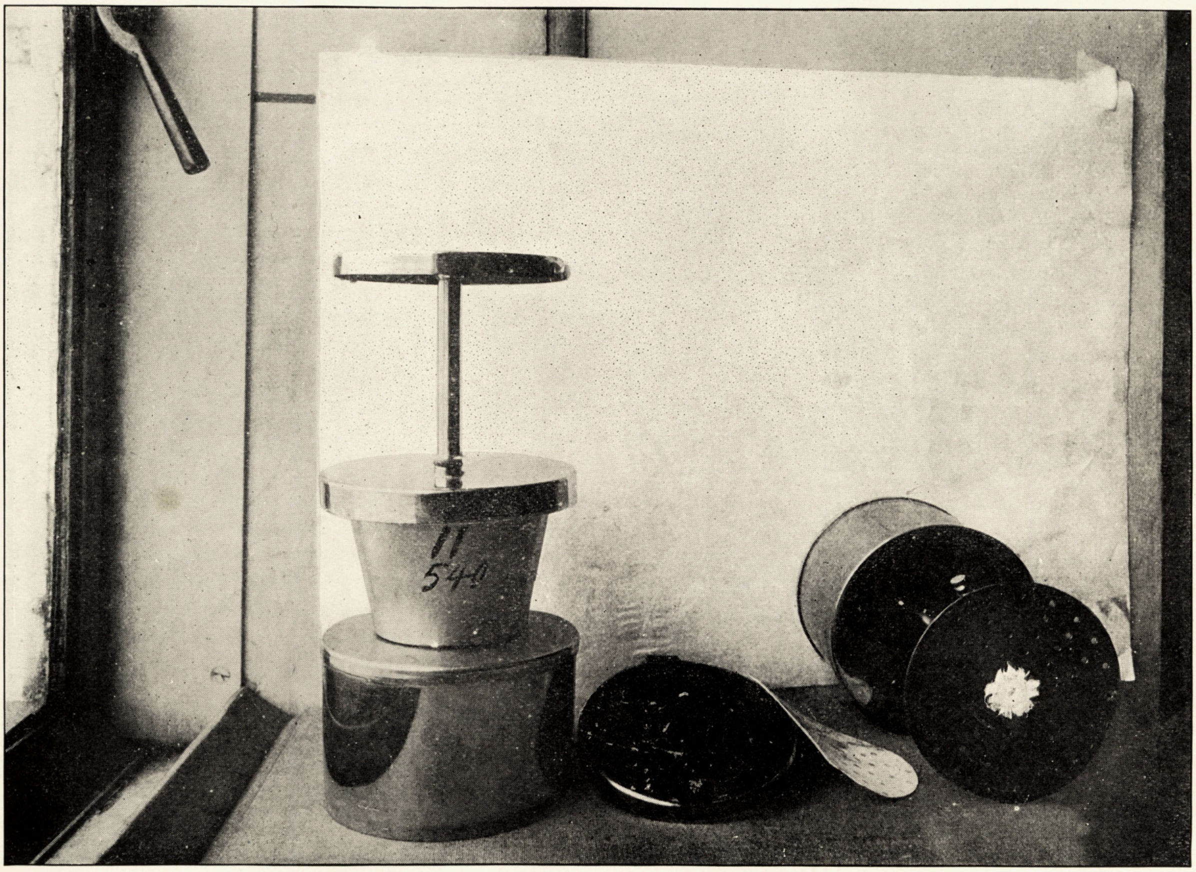

FIG. 2.—Type 4 Evaporimeter. On the left, complete instrument resting on its inverted base or shell, as for weighing. On right, instrument with disk exposed, showing perforations and end of stem wick. In center, blackened cover, and disk wick, which is stained, after 6 months' use.

linen wick, held in position by having its top edge turned over the rim of the metal cylinder and covered by a clamp band. The wick was long enough to reach down into the water, and to practically close the metal funnel. There was thus exposed on the interior of the second wall of the instrument a moist surface calculated to be about 189 square centimeters, practically removed from any heat which the walls of the instrument might absorb, and receiving its heat primarily through a horizontal opening of 10 sq. cms. area, which would, of course, illuminate different portions of the wick at different hours.

Two difficulties were experienced in the operation of this instrument. First, it was not found, as had been hoped, that the rain or snow taken in through the 10 cm. opening could be accounted for by measuring the depth of precipitation in an ordinary gage. The amount "shipped" was occasionally more, but usually less than the area of the opening would imply, and while usually a small factor as compared with the evaporation from 189 cms. of wick, could never properly be ignored. Secondly, the hood used to exclude sunlight from the opening of the "shade" instrument undoubtedly interfered with air movement and diffusion as shown by comparison of the instruments at night. For these reasons the comparisons of the two kinds of instruments were often vitiated, and as correction can not be made for precipitation absorbed by the "sun" instruments, only the records of the "shade" have been used for any purpose.

Type 3 was very similar to Type 2. To make sun and shade instruments equal as to air circulation, however, the air was admitted between the top edge of the outer shell and the flange of the conical cover, the latter being raised about 1 centimeter. The wick was placed on the *outside* of the interior cylinder, while the inner surface of the latter was blackened to absorb such sunlight as should reach it. It was expected that the heat would be conducted through the metal cylinder to the wick on its outer surface. This it did not do satisfactorily. To account for precipitation, which, as in Type 2 might enter the "sun" but not the "shade" instrument, the inner cylinder was sealed at its lower end, the plan being to withdraw accumulated water before weighing for water-loss. This instrument was only tried long enough to show that the practical difficulties had been overcome, inconvenience had been created, and the technical features of the Type 2 had been practically destroyed, as the sensitiveness to sunlight was much weakened, and the sensitiveness to air movement greatly increased.

Type 4 was evolved at almost the same time as Type 3 and was placed in service at a number of stations in January, 1917. (See figures 2 and 3.)

The essential features are:

1. A light, seamless copper tank, slightly larger at the top than bottom, to facilitate spinning and also, possibly, to somewhat relieve ice pressure on the bottom of the tank, it having been noted that after a vessel has been somewhat rounded on its bottom by ice pressure, further freezing within it does not cause appreciable change of shape. The capacity of the tank is about 450 cc.

2. An outer, polished shell, somewhat larger than the tank, to protect the tank from insolation, to keep it clean, to furnish a larger base for the instrument, and to be removed in weighing.

3. A hollow stem of strong brass tubing, opening into the upper portion of the tank at its center, and surmounted by a horizontal metal disk about 10 cms. above the tank. In this stem is placed a linen wick, made by rolling a piece of the heaviest damask about 7 inches square, the threads being drawn on one edge so that when rolled the upper end may be flattened out into a rosette.

4. The horizontal metal disk has a diameter of 11.27 cms. (4.44 inches) giving it an area of 100 square centimeters. It is of 16-gauge brass, or approximately one-sixteenth inch thick. It is perforated by 64 drill holes made with one-eighth-inch drill, giving a total area of openings of about 5 square centimeters. The stem wick projects slightly above the level of this disk, the end of the wick being flattened out, in a rosette, as aforesaid.

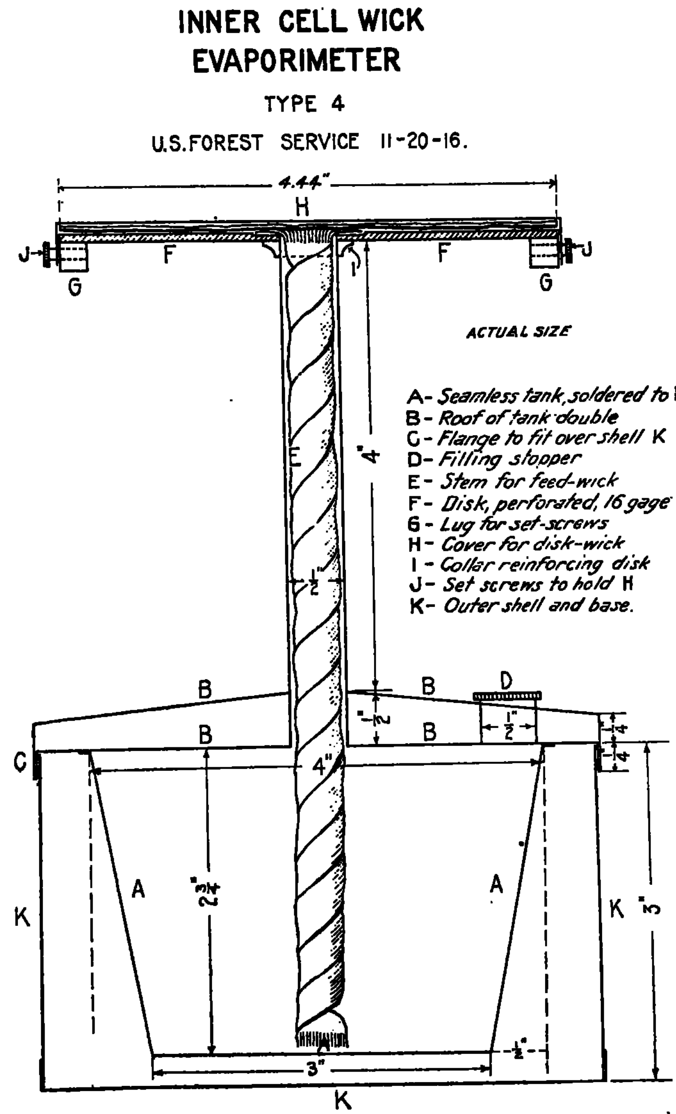

FIG. 3.

The disk wick, a flat piece of similar heavy damask, is then laid on the rosette. The disk wick should be cut about 4.2 inches in diameter to cover the disk fully when moist.

5. The cover is flat, barely larger than the disk, and having a 1 cm. flange which covers the edge of the disk when in position. In this flange are two notches or slits, engaging sets screws on the edge of the disk. Holding the cover down firmly against the wick, the screws are set. The cover, and all exterior surfaces of the instrument are nickeled and polished. The polished cover absorbs very little of the energy of sunlight, while a coating of lampblack and turpentine gives it high

absorbing qualities. This coating is fairly durable under weather action, yet can be removed without affecting the nickel coating. Mixing the lampblack with turpentine gives a fair binding quality without any luster such as would result from ordinary paint mixtures.

Once the cover has been set against the wick, it should not be removed unless absolutely necessary, since any change in its position will affect the degree of contact between the cover and the wick, and hence the extent to which the heat absorbed by the cover is conducted to the wick and is effective in evaporation. The cover should be set before calibrating and then not disturbed until it becomes necessary to freshen wicks.

It is evident that, while there are 100 square centimeters of moist wick under the cover, and an equal blackened area exposed, in a horizontal plane, to the sun, only 5 per cent of the area of the wick is exposed to the air, and even this not directly, but in a recess at the end of a pit, whose opening is downward. We may conceive that vaporization occurs throughout the mass of the wick, and that such vapor as is formed in the spaces between the disk perforations, must pass through the meshes of the linen before it can escape. No part of the wick is exposed directly to air moving over its surface. The conditions under which vapor is formed, but more particularly the conditions under which it escapes, are, then, on a gross scale not dissimilar to those existing in the leaf.

PRACTICAL DIFFICULTIES AND ADVANTAGES OF THE TYPE 4.

Before considering the behavior of this instrument in relation to transpiration of plants, I wish to describe its practical features. Without in any way exaggerating its advantages, I will simply say that the present development represents the best result of my own experience and difficulties and I can find no feature of the Type 4 evaporimeter which is objectionable, unless it be the rather small volume of the evaporation in short periods.

Weight.—The net weight is between 500 and 600 grams, without the outer shell or base, which is always removed before weighing. With the tank filled, the gross will usually be about 1 kilo, and portable scales of this capacity are readily obtainable which are fairly sensitive to 0.1 gram, so that there is no difficulty in obtaining all needed precision for measuring long-term losses. Since a loss of 40 grams in 24 hours is exceptional under mountain conditions, it is seen that less than the capacity charge of water will ordinarily suffice for weekly intervals.

Compactness.—Being entirely of metal, and practically cylindrical in general outline, the instrument may be wrapped in heavy paper and packed in almost any box, or carried even in a sack, without danger of injury.

Feeding.—The linen used for both stem and disk wicks has strong capillary properties, and if clean will readily moisten to the extreme edges of the wick within an hour or two of the time of filling the tank. The capacity of the wicks to supply rapid evaporation losses has never been seriously taxed. Of some 30 instruments in use during part or all of 18 months, only 2 have shown any inclination to overfeed and drip. The exact cause of this could not be traced, but it was probably due to stem wicks being too tight, causing water to be forced up in them under air pressure, as the tanks warmed in the middle of the day. No dripping as a result of wetting by fog or rain has ever been noted. One or two instruments have at times absorbed rain water, which flowed over the edge of the cover and entered around the set screws. This is not likely to happen, however, if the notches for the set screws are properly cut, and can be prevented by using rubber gaskets below the heads of the screws.

SOILING AND REPLACEMENT OF WICKS.

The instruments have been used in a remarkably dust-free region, and hence any soiling of the exposed portion of the disk wicks is practically unknown. After six months' use with distilled water, however, both stem and disk wicks, but especially the latter, are likely to be considerably stained with oxides of copper, and their removal, or at least a thorough washing, is desirable, since, of course, the greatest accumulation of such material will be in the small sections exposed to the air. Nothing but distilled water may be used, since even the solutes in filtered water would immediately cause accumulations at the evaporating points. In a region where there is considerable dust, undoubtedly much shorter life of the wicks is to be expected, if good results are to be had. The position of the openings on the underside of the disk, however, reduces this aggravation to a minimum. As with porous clay atmometers, the real danger with proper handling is to be looked for in the action of water on the instrument itself. One must not wait until the capillary properties of the linen are destroyed, since *any appreciable quantity of soluble matter in the water to be evaporated will affect the evaporation rate.*

Calibration.—No effort was made to calibrate the several instruments in use until the season of 1918, so that the possibilities in this line have not been fully tested. Testing ordinarily for periods of a week, however, the 30 instruments have shown ratios to the standard ranging from 0.785 to 1.230. The great majority, however, fall between 0.900 and 1.000, the standard, taken arbitrarily from among the first instruments made, losing a little more water than the average of the others. Successive calibrations on the same instrument usually give very consistent results, but it is possible, by changing wicks, by resetting covers in somewhat different positions, and by altering the environmental conditions for calibration, to obtain quite variable results. In other words, no two instruments respond exactly the same to changes in environment, though doubtless their responses are more similar than would be the responses of an instrument and a plant. Of all the factors causing variation in and between instruments, the position and contact of the cover with the wick seem by all odds the most important.

It is evident from the variations between instruments that none should be used without standardizing, although, however carefully this is done, it will not cover all possible field conditions. After standardizing great care should be used not to disturb the relation between the absorbing cover and the wick.

BEHAVIOR OF INSTRUMENTS IN RELATION TO TRANSPIRATION OF CONIFEROUS TREES.

As has been stated, some of the ideas as to the qualities which an atmometer should possess were gained through Burns's results in comparing the transpiration of pine seedlings with evaporation from black and white porous cups. The writer has not been particularly interested in, nor has he had opportunity to consider the transpiration behavior of herbaceous plants. During 1917, however, the daily transpiration losses of 12 small coniferous trees were determined over a period of more than 5 months, and during most of this time several types of atmometers were operated on the same table with the plants. In all there are 116 periods, mainly of 24 hours each, in which some or all of the atmometers may be compared with the plants.

Atmometer ratios for different kinds of days.—The 116 periods have been divided into days of ten classes: first, according to the duration of sunlight, and secondarily according to the estimated amount of air movement. It should be understood that with the exception of one day all of the exposures were made in the greenhouse on a table which during a part of the time was moving steadily and with sufficient speed to create some circulation about the plants. During a larger part of the time, however, it was moved only periodically. Part of the time the greenhouse was closed quite tightly, and at other times ventilators were opened enough to produce considerable draft. The periods divide themselves roughly then into (1) those with no ventilation, (2) those with only the circulation caused by rotation of the table, and (3) those with an appreciable amount of natural air circulation. Group 2 is sufficiently represented to be considered separately only for the larger group of days having 201–500 minutes of sunshine. In addition, it is necessary to consider the single day out-of-doors in a class by itself, as the amount of air movement was out of all proportion to that in the greenhouse.

Table 1 shows for each type of atmometer the average ratio of its loss to the total transpiration of the 12 plants for each kind of day, as also the number of periods on which the average is based. In addition, there is shown the average daily amount of transpiration for each class of days. All of the ratios of evaporation to transpiration are given as percentages.

TABLE 1.—*Average ratios of evaporation to transpiration for different kinds of days.*

Character of exposure.			Instrument.													Amount of transpiration (average per day).
Sunshine.	Ventilation.		No. 2, sun.	No. 3, shade.	No. 3, sun.	No. 4, shade.	No. 4, sun.	No. 4, sun, 1-gauze.	No. 4, sun, 2-gauze.	No. 4, sun, 3-gauze.	No. 4, glass.	Livingston white.	Livingston black.	Piche shade.	Piche sun.	
None	None	Number days	14	4	4	3	9	8	6	6	8	9	9	4	8	9
		Ratio	2.67	13.16	13.50	6.15	7.29	6.45	5.79	6.32	7.92	27.94	27.92	22.06	25.82	49.8
	Ventilation	Number days	5	5	5	3	8	8	5	5	7	7	8	5	8	9
		Ratio	3.29	13.80	15.00	6.27	7.52	6.56	6.35	7.38	8.31	33.66	32.76	23.76	28.26	56.7
1-200 minutes	None	Number days	6	6	6	2	8	7	6	6	8	7	8	6	8	9
		Ratio	1.74	6.16	6.24	3.98	4.23	3.58	3.19	3.67	4.19	13.97	14.87	11.28	12.27	90.1
	Ventilation	Number days	13	13	13	5	14	14	7	7	13	13	12	13	14	20
		Ratio	2.25	7.94	8.64	4.15	4.71	4.06	3.93	4.51	5.04	18.18	18.39	13.87	15.22	66.8
201–500 minutes	None	Number days	6	6	6	0	9	9	9	9	9	9	9	6	9	10
		Ratio	1.54	6.29	6.20	....	4.71	4.07	3.56	4.04	4.45	10.59	11.33	7.94	9.84	160.0
	Rotation	Number days	2	2	2	2	2	2	0	0	2	2	2	2	1	2
		Ratio	2.24	5.06	5.74	2.91	3.88	3.22	....	....	3.76	7.13	9.35	4.84	5.51	141.8
	Ventilation	Number days	37	37	37	27	46	45	19	19	32	44	46	36	45	48
		Ratio	2.76	7.82	8.86	3.49	4.50	3.86	3.38	3.94	4.24	12.38	13.82	8.24	10.48	170.5
Over 500 minutes	None	Number days	6	6	6	5	6	5	1	1	1	6	6	6	6	6
		Ratio	3.57	7.98	9.22	5.54	6.66	6.09	3.54	3.59	3.78	10.96	12.62	8.57	9.44	180.8
	Ventilation	Number days	13	13	13	12	13	10	1	1	5	11	13	13	12	13
		Ratio	4.28	9.78	10.66	4.60	6.13	5.37	3.77	3.72	5.48	13.22	15.26	10.27	11.30	205.8
	Wind	Number days	1	1	1	1	1	1	1	1	1	1	1	....	....	1
		Ratio	10.13	24.29	26.67	9.96	5.45	6.30	9.06	7.79	10.60	20.72	26.00	14.45	....	228.5
Average ratio			3.45	10.22	11.07	5.13	5.51	4.96	[1] 4.73	[1] 5.00	5.78	16.88	18.23	12.53	[1] 14.24	....
Sum of variations			15.19	41.01	43.89	13.02	11.14	11.88	13.02	13.02	19.01	66.01	64.28	48.06	53.18	....
Average variation			1.52	4.10	4.39	1.45	1.11	1.19	1.45	1.45	1.90	6.60	6.43	4.81	5.91	....
Per cent of variation			44.0	40.1	39.6	28.3	20.2	24.0	30.7	29.0	32.9	39.1	35.1	38.4	41.5	....

[1] Not complete for all classes of days.

REMARKS ON TABLE 1.

1. In the cases of Type 3 Inner-cell, Type 4, and Livingston porous-cup, the variations from the average ratio to transpiration are less for the so-called "sun" instruments than for the corresponding type which absorbs sunlight less completely. This indicates plainly the need for complete sunlight absorption to obtain a response similar to that given by the plants. The failure of the Piche to show this relation is doubtless due to the fact that the fully-insolated paper often becomes dry at the edges or otherwise fails to evaporate to capacity under strong sunlight.

2. In the Type 3 Inner-cell, and in the Livingston porous-cup, and Piche instruments, both "sun" and "shade" instruments show very high ratios when sunlight is deficient, owing to the free exposure of the evaporating surfaces to moving air. In all types the response to a small amount of sunlight is less than with plants.

3. Essentially the same instruments show decided increases in ratio with increase in the amount of ventilation in each sunshine group. All of the Type 4 instruments show this increase less markedly. The plain Type 4 "sun," without gauze, is especially steady under the influence of increased circulation, and its behavior on the single day with "wind" (out-of-doors) is truly remarkable. It is not desired to lay too much stress on this single record. It is to be noted, however, that the Type 4 1-gauze "sun" behaved similarly, the other Type 4's, being less similar. The behavior of the Type 4 "shade" is similar to that of the free-surface Piche and Livingston instruments. This indicates that the principal effect of air movement, in increasing evaporation, may arise through supplying heat to the evaporating surface rather than by assisting in any material degree in accelerating diffusion of the vapor molecules, for in the latter respect the influence on the "sun" and "shade" instruments of Type 4 should have been the same. We then see that on days with a large amount of sunshine the blackened Type 4 is not accelerated by wind, more than are the plants, because both may be slightly warmer, at least superficially, than the air. Air movement may, therefore, carry away heat, almost as largely as it brings heat.

4. All things considered, the Type 4 "sun" instrument behaves, under a variety of conditions, most like the plants, and the others show wider variation about in proportion to the degree in which they expose the evaporating surface to moving air and fail to absorb fully

the heat of sunlight. The Type 2 "sun" is an exception in that it is not responsive to small amounts either of sunlight or of air movement. Its actual losses are very small, in proportion to the wick area exposed, indicating that they are too largely controlled by the small opening at the top of the instrument, which being considerably removed from the evaporating surface, creates altogether too much of a dead-air space within the chamber.

The Type 4 with various layers of gauze, and that one in which glass was substituted for the metal cover, are not superior to the original conception. It should be said that the layers of fine, brass gauze, of the same size as the disk wicks, were placed beneath the wicks in the hope of increasing the total evaporation by facilitating the movement of vapor toward the "stomatal" openings. Instead, they have evidently had the effect of creating a larger chamber for vapor storage, a dead-air space as in the Type 2, and have removed the wick further from the influence of the disk, which might at times be a source of heat.

It may be said to overcome objections, that if we should eliminate from consideration the single day with "wind" whose influence on the final result for Type 4 "sun" is negligible, this instrument would still stand superior to the others. Its percentage of average variation would then be 22.3, as against 34.5 per cent, for example, for the blackened Livingston cup.

INSTRUMENTAL VARIATION FOR SIMILAR DAYS.

Does any type of instrument show a constant relation to transpiration if the environmental conditions remain constant?

This question could undoubtedly be answered in the affirmative if we were speaking of successive periods alike in every respect, and not in any degree taxing the capacities of either plants or instruments, or producing progressive changes in them.

With the present data we can only compare days having a general resemblance. It is to be noted that days with 201–500 minutes of sunshine and with some ventilation are most numerous as shown by Table 1. We shall, therefore, analyze this group. In Table 2 the instruments are compared for days of this class.

TABLE 2.—*Variability of instruments for days of similar sunshine and air movement.*

Datum.	Type of instrument.												
	No. 2 sun.	No. 3 shade.	No. 3 sun.	No. 4 shade.	No. 4 sun.	No. 4 sun, 1-gauze.	No. 4 sun, 2-gauze.	No. 4 sun, 3-gauze.	No. 4 glass.	Livingston, white.	Livingston, black.	Piche shade.	Piche sun.
Average ratio to transpiration (per cent)	2.76	7.82	8.86	3.49	4.50	3.86	3.38	3.94	4.24	12.38	13.82	8.24	10.48
Number of periods	[1] 37	[1] 37	[1] 37	[1] 27	46	45	[2] 19	[2] 19	[2] 32	44	46	[1] 36	45
Sum of variations (per cent)	20.42	49.65	53.57	17.75	34.16	31.02	10.56	11.45	21.98	132.31	122.92	56.27	114.87
Average variation from average ratio (per cent)	.552	1.341	1.447	.658	.743	.690	.556	.603	.687	3.008	2.671	1.563	2.551
Per cent of average variation	20	17.2	16.3	18.8	16.5	17.9	16.4	15.3	16.2	24.3	19.3	19	24.3

[1] Deficient at end of season. [2] Deficient at beginning of season.

The No. 4 "sun" instrument is seen here to be among the least fluctuating of the instruments with environmental conditions not going to any great extremes either as regards sunlight or air movement. The most variable, in order, are the Piche "sun" and white porous-cup, No. 2 "sun," black porous-cup, Piche "shade" and No. 4 "shade."

No. 3 "sun" and Nos. 4 with 2-gauze, 3-gauze, and glass variations, show themselves as consistent, or more consistent in relation to transpiration than the regular No. 4 "sun." These, however, are all deficient as to time; that is, they did not experience the entire range of conditions to which the others were subjected. The full significance of this will be seen in the next paragraph. If we compare Type 4 "sun" with Type 4 3-gauze, which shows the least variation, in the period in which the latter was operated, the variation is only 14.6 per cent for Type 4 "sun." It only seems safe to say that the Type 4 group, as a whole, adheres most closely to transpiration rates, and this in spite of the fact that its actual evaporation losses are small and the variation due to inaccuracy in weighing should be a larger factor.

The variations for days of this general class, ranging from 16 to 24 per cent, are still large and still leave open the question whether under uniform environmental conditions plants and evaporimeters may accord, which is really a question of whether the plants themselves are governed closely by exterior physical conditions or exercise some control in the vitalistic sense.

For better data on this point we may refer to the period November 2–8, inclusive, when the weather conditions were very uniform, the greenhouse was constantly ventilated, and there was no artificial shading. The duration of sunlight in these seven days varied from 376 to 477 minutes per day, the morning vapor pressures from 0.121 to 0.189 inches, and the daily transpiration totals from 151.4 grams to 127.9 grams. As these are all moderate amounts, we can not conceive of the plants being seriously taxed or suffering any cumulative changes. Under these conditions the following mean variations of the evaporimeters are noted, which are really quite reassuring as to the possibilities of atmometry.

	Per cent.
No. 4 "sun"	4.2
No. 4 "sun," 1-gauze	6.3
No. 4 "sun," 2-gauze	5.9
No. 4 "sun," 3-gauze	7.5
No. 4 glass	7.8
Livingston, white	8.7
Livingston, black	4.6
Piche "sun"	7.1

Seasonal ratios to transpiration.—It has been brought out in the study of the transpiration of the trees that toward the end of the season the total transpiration decreased slightly in proportion to the atmospheric stresses. For a given set of conditions there was, at the close, somewhat less transpiration than for similar conditions in the early part of the season. This change was thought to be due to the aging and thickening of leaf epidermis as the season advanced and to increased solutes in the cell sap. The marked change, however, was restricted to one specimen of Douglas fir, apparently in an unhealthy state.

Such being the case, we should expect the ratios of instrumental evaporation to transpiration to increase toward the end of the season. Table 3 shows what actually happened. Only the days with 201–500 minutes of sunshine and with some ventilation are considered.

TABLE 3.—*Ratios of evaporation to transpiration at different times in the season.*

Datum.	Type of instrument.				
	No. 4, sun.	No. 4, sun, 1-gauze.	Livingston.		Piche, sun.
			White.	Black.	
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Average ratio for all days of this class	4.50	3.86	12.38	13.82	10.48
First 10 days, June 8–27	5.22	4.45	12.42	14.04	11.16
Middle 10 days, Aug. 1–28	3.85	3.14	[1] 10.38	12.48	8.46
Last 10 days, Oct. 9–Nov. 8	4.88	4.24	17.64	18.30	14.73

[1] Only 9 days.

For all types of atmometers having this complete record the ratio is lowest at midseason.

For the Type 4 "sun" and its counterpart, the evaporation is relatively less at the end of the season.

For the Livingston cup, and the Piche, the evaporation rate is higher at the end of the season. This is what should be expected *if* the transpiration did decline, for the Livingston cups, at least, being spherical, would hardly be affected by the low elevation of the sun late in the season. The similar performance of the Piche is difficult to explain.

The behavior at midseason is difficult to explain except on the ground of free transpiration in the trees as a whole, which apparently existed. Such vigorous transpiration may possibly be accounted for by the completion of new growth and the lack of concentrated solutions and of thickened cell walls in the leaves.

The behavior of the Type 4 instruments indicates that the horizontal surface exposed to the sun is not all that might be desired for the study of individual plants. It should be stated that this kind of surface was definitely striven for in the view that in forest studies we are not so much concerned with the conditions affecting the individual plants as with, for example, the evaporation per unit of ground area. This view, however, is seen to be untenable in considering the factors which control the fate of the seedling and in large measure the ecological distribution of the species, for the individual seedling is a unit of itself, and half a million other seedlings on the same acre would hardly affect its response to evaporation stimuli.

It is seen, however, that the Type 4 "accidentally" takes care, pretty well, of the decreased tendency toward transpiration after the apex of the season is passed.

Daily periodic evaporation and transpiration.—As a further check of the various types of atmometers against the behavior of plants, both were measured on a bi-hourly basis for one day, October 27, 1917. The day was clear after 9 a. m. and before 4 p. m., showing 436 minutes of sunshine out of a possible of 634. The greenhouse was kept closed, so that there was no air circulation except that created by the movement of the table. Artificial heat was used in the latter part of the day and at night, so that the temperatures were very high and tended to tax the transpiration capacity of the trees.

Before considering the relation of the evaporation from instruments to that from the trees, it will be well to note the behavior of the trees with relation to the environmental conditions. This is made possible by frequent observations on humidity and by frequent checks of the black-bulb temperatures recorded by the thermograph. As has been discussed in another paper (1) the saturation deficit expressed by the difference between actual vapor pressure and saturation pressure corresponding to the "sun" or black-bulb temperature, in the absence of appreciable air circulation would appear to control most directly the rate of diffusion of the vapor from plants. In the present case, the relations would not be materially changed if we considered the plant temperatures reduced by an amount, for example, equal to the wet-bulb depression, which would be about the only basis for correcting the recorded "sun" temperatures.

The data on which Diagram 1 is based are shown in the following table:

TABLE 4.—*Environmental conditions affecting periodic evaporation on Oct. 27, 1917.*

Datum.	Condition observed at—							Mean for period centering at—					
	7:28 a.	9:28 a.	11:27 a.	1:30 p.	3:28 p.	5:33 p.	7:00 a.	8:30 a.	10:30 a.	12:30 p.	2:30 p.	4:30 p.	12:15 p.
Sun temperature [1]	41.9	62.9	94.5	100.0	99.2	64.8	52.5	49.5	80.0	104.0	106.5	88.0	[3] 63.3
Saturation pressure [2]	....	....	....	....	....	....	....	.354	1.022	2.160	2.326	1.322	.581
Dry-bulb temperature	41.4	60.9	80.0	90.0	82.0	68.1	53.6	....	....	....	....	....	....
Wet-bulb temperature	38.4	50.8	60.5	69.3	61.7	53.2	46.8	....	....	....	....	....	....
Vapor pressure [2]	.206	.282	.360	.528	.379	.282	.263	.244	.321	.444	.454	.330	.272
Saturation deficit	....	....	....	....	....	....	....	.110	.701	1.716	1.872	0.992	.309

[1] Means for periods computed from thermograph record.
[2] Computed from table for barometric pressure 23 in., as local table does not reach highest temperatures.
[3] Temperature held up after 5:30 p. m. by artificial heat, going as high as 70° F. at 10 p. m.

Diagram 1 (fig. 4) indicates that the rate of transpiration is proportionate to the evaporation stresses, as measured by saturation deficits, until practically through the period ending at 1:30 p. m. Then it falls very rapidly, though the atmospheric stress is even greater in the next period. During the afternoon and night the curve returns at a lower level, apparently approaching its original base at the beginning of the second day.

There are several possible explanations of this diurnal curve:

1. The stomata may close when the highest transpiration rate is attained.

2. The morning transpiration may be in excess of water intake, thus tending to produce a gradually more concentrated solution in the leaves. If this alone were the cause, however, we should not expect such a marked drop in rate for the period 1:30 to 3:30 p. m., and we should expect more rapid recovery to the morning rate, since in the period mentioned the loss was scarcely greater than from 9:30 to 11:30 a. m.

3. The morning transpiration rate may be accelerated by the *rise* in temperature, as discussed in the theoretical phases of the subject. In this instance the highest sun temperature was recorded just about 1 p. m., but there was a secondary rise of about 5° F. an hour later. The greatest sunlight intensity was probably at noon or a little before.

That the sudden decline in transpiration rate soon after noon is not due either to the factor described under (1) or

(2) above may be determined by inference from an examination of the behavior of the different species which comprised the group of 12 trees. In fact, one yellow pine showed a slight increase while the other trees were decreasing. The behavior of the species is shown by diagram 2 (fig. 5). Comparing the loss in the fourth

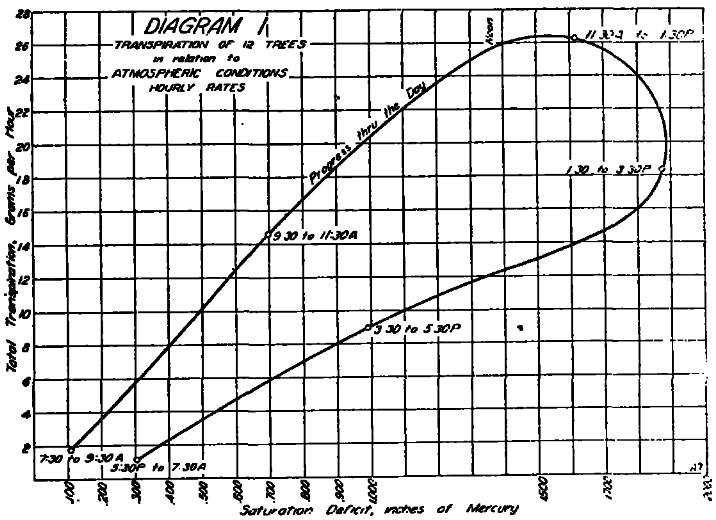

FIG. 4.

with that in the third period, for each species, we obtain the following relations:

Species.	Loss immediately after highest temperature relative to that before the maximum.
Yellow pine	0.972
Bristle-cone	.728
Limber pine	.650
Engelmann spruce	.617
Lodgepole pine	.450
Douglas fir	.387

The behavior of the last two species adequately banishes the idea that reduction of transpiration is due to exhaustion of either the plant water or soil moisture. The species showing the least total loss is most reduced; that showing the greatest most nearly maintains its rate. As between these extremes, we believe the difference to be one primarily dependent on the condition of the trees. The transpiration of lodgepole and Douglas fir, relative to the whole, had been declining for some time prior to this test. We may, therefore, conceive that they were in a state of maturity, represented by thickened walls, dense sap, and possibly closed stomata, such that sunlight penetrated their walls with difficulty, and the vapor formed was forced through the stomata under considerable pressure. With the first decrease in temperature and sunlight intensity, therefore, the internal pressure falling, the vapor escaping is much reduced. In short, if we conceive that the avenues for escape are much restricted, the rate of loss becomes little dependent on the saturation deficit, or differential, but almost wholly on the absolute internal vapor pressure.

With the other four species, all of which appeared to be functioning at this time much the same as in the early part of the season, we may believe that there was much less mechanical restriction upon transpiration. In a rough way, their respective declines after the diurnal maximum of radiation, appear to be related to the density and arrangement of their foliage. The leaves of the yellow pine, forming almost a rosette, are open both to sun and air temperature influences almost as much at one time as another. The compact foliage and erect form of spruce may be such as to induce the maximum of insolation of the foliage with the sun at the zenith. Bristle-cone and limber pines stand in intermediate positions in this respect.

It is believed, then, that the general decline in transpiration rates before the maximum atmospheric stresses appear to occur is primarily a question of insolation of the foliage and of resistance to vapor diffusion due to a fixed condition in the plants, such that the internal vapor pressures are in a sense cumulative, and with any decrease in the leaf temperatures, immediately following lessened insolation, there is a decided tendency toward condensation and toward curtailment of diffusion, even if saturation deficits as measured by temperatures outside the plants, remain high.

The correct analysis of the situation is important in this discussion; for if the above is true, we may hope to simulate the plant condition in a mechanical contrivance. If the decline is due to stomatal movement or to increasing sap density, primarily, we can not hope to duplicate the conditions in any automatic instrument.

That the insolation received, and the actual temperature and absolute vapor pressure at the point of vaporization control more largely than the saturation deficit, is shown by the behavior of all the atmometers which absorb sunlight sufficiently to reflect a "sun" temperature of their own.

Table 5 shows the periodic data for instruments and trees. Diagram 3 (fig. 6) shows the same data on a basis of hourly rates.

TABLE 5.—*Periodic evaporation Oct. 27–28, 1917.*

Period.	Type of atmometer.									Total all instruments.	Total transpiration.
	No. 4 sun.	No. 4 1-gauze.	No. 4 2-gauze.	No. 4 3-gauze.	No. 1 glass.	Livingston, white.	Livingston, black.	Piche sun No. 1.	Piche sun No. 2.	*Grams.*	*Grams.*
7:30–9:30 a	0.20	0.10	0.05	0.25	0.15	0.65	0.60	0.50	0.50	3.00	3.5
9:30–11:30 a	1.20	1.20	0.85	0.75	1.05	1.50	2.25	1.90	1.80	12.60	29.0
11:30 a.–1:30 p	2.95	2.10	2.05	2.60	2.15	3.15	5.60	5.60	5.00	31.20	52.4
1:30–3:30 p	2.25	1.65	1.40	1.30	1.70	4.15	4.50	3.80	3.90	24.75	36.6
3:30–5:30 p	0.85	0.9	0.8	0.85	1.0	2.9	2.9	2.7	2.9	15.80	17.8
5:30 p–7:00 a	2.80	2.45	2.30	2.70	3.20	11.60	12.30	9.50	9.20	56.00	14.5

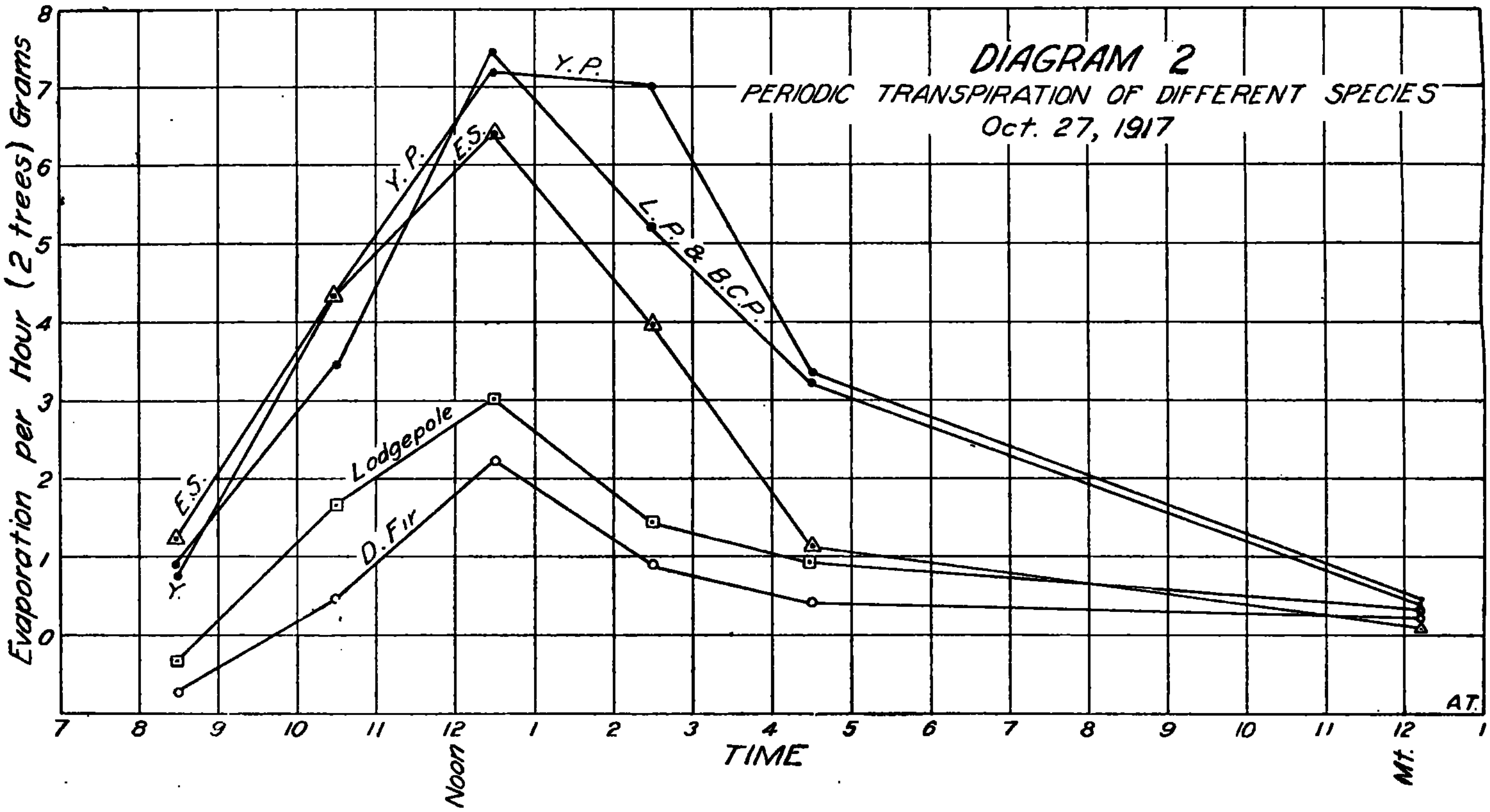
DIAGRAM 2
PERIODIC TRANSPIRATION OF DIFFERENT SPECIES
Oct. 27, 1917
Evaporation per Hour (2 trees) Grams
Y.P.
E.S.
L.P. & B.C.P.
Lodgepole
D. Fir
Y.
TIME
Noon
Mt.
A.T.

FIG. 5.

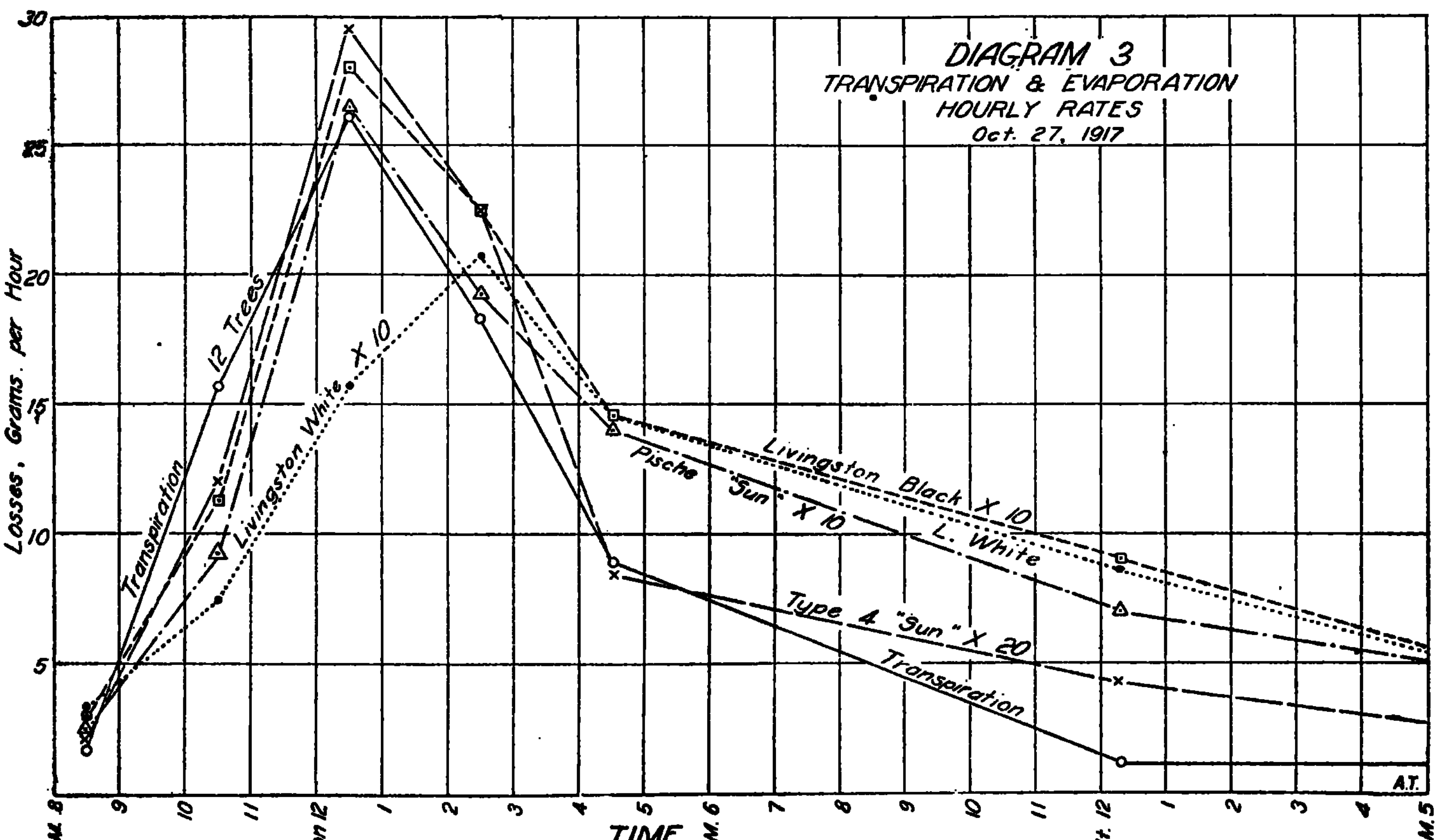
DIAGRAM 3
TRANSPIRATION & EVAPORATION
HOURLY RATES
Oct. 27, 1917
Losses, Grams per Hour
Transpiration
12 Trees
Livingston White X 10
Livingston Black X 10
Piche "Sun" X 10
L. White
Type 4 "Sun" X 20
Transpiration
TIME
A.M. 8
Noon 12
P.M. 6
Mt. 12
A.M. 5
A.T.

FIG. 6.

A study of diagram 3 (fig. 6) shows that if the evaporation from the instruments be increased by such factors that at the highest point their losses approximately equal the total transpiration, (1) all except the white porous cup show a sharp decline with the first decline in transpiration; (2) the white porous cup shows its dependence at all times on atmospheric conditions rather than on "sun" temperatures; (3) the porous cups and Piche types show five to seven times as much evaporation at night as do the trees; (4) the Type 4 "sun" instrument more closely follows the trees at night because dependent, like them, on radiant energy rather than heat of the air.

These are essentially the same relations shown by the comparative behavior in different kinds of days.

SUMMARY.

The Type 4 "sun" wick evaporimeter represents the most complete development of an effort to duplicate by mechanical construction the physical features of the plant which control basically its response to evaporation stimuli. The important features, physically, are (1) the blackened surface of the cover, absorbing the energy of sunlight to a high degree, and transmitting this energy by conduction through brass to the moist wick immediately beneath and in contact with the cover; (2) the position of the wick, removed from immediate contact with the outside atmosphere, so that the air itself is not an important source of heat for evaporation, and so that vapor formed between the disk perforations, corresponding to stomata, does not diffuse too readily to the outer atmosphere.

These features permit the type 4 wick evaporimeter to follow plants, through wide variations in sunlight and air movement, more closely than any other atmometer which has been used or tested in the present case. Moreover, under rather uniform conditions, from day to day, the relations of evaporation to transpiration, with this instrument, are more consistent than with others, in spite of the fact that the actual losses are relatively small and the possibility of variations due to inaccuracy in weighing proportionately great.

The "shade" or polished-top evaporimeter of Type 4 possesses no advantages over the "sun" instrument, and the operation of the two phases side by side offers no possibilities as a means for measuring sunlight intensities, or even as a means for showing the extent to which plants are influenced by sunlight.

The essential points in the operation of the Type 4 evaporimeter are:

1. The use of distilled water.
2. Replacement of wicks whenever they become soiled at the edges or at the points most directly exposed to the air.
3. The use of heavy damask for wicks, because of its strong capillary properties and large capacity.
4. Calibration whenever it becomes necessary to replace wicks or to remove the cover.
5. Firm placing of the cover to obtain close contact with disk wick.
6. The use of scales having a capacity of 1 kilo and a sensitivity of 0.1 or 0.2 gram.
7. In freezing weather it is preferable to maintain the water in the tanks at the lowest level commensurate with the needs of daily or weekly evaporation periods. It is never desirable to fill the tanks to capacity.
8. Lampblack mixed with turpentine to the consistency of a thin paste, and applied with a camel's-hair brush, is the best coating for covers so far tried. It should be retouched or replaced whenever any considerable area of the nickeled surface shows through. Ordinary paint, with a luster, should be avoided. Certain "dead-black" paints are fair substitutes for lampblack.
9. The exterior polished surfaces of the instrument should be kept clean so that they do not become absorbers of insolation in any marked degree.
10. The instruments are preferably placed on the ground, or, if above the ground, in baskets which do not create any artificial reflecting surfaces below the disk, other than those of the instrument itself.

The present development has produced an instrument which is eminently practical in addition to integrating solar and atmospheric conditions in much the same way as does the plant. No new difficulties are encountered in attempting to use it for year-long climatological studies.

LIST OF REFERENCES.

1. BATES, C. G. "Forest Types of the Central Rocky Mountains in relation to Environmental Conditions."

2. BURNS, G. P., and HOOPER, F. P. "Studies in Tolerance of New England Trees: II. Relation of Shade to Evaporation and Transpiration in Nursery Beds." (Vermont Agr. Exp. Sta., Bull. 181, 1914, Forest Service Publ. No. 15.)

3. LIVINGSTON, B. E. "Atmospheric Influence on Evaporation and its Direct Measurement." (MONTHLY WEATHER REVIEW, March, 1915, vol. 43, pp. 126–131.)

(This is only one of the latest of numerous papers by the same author describing the porous cup atmometer, and contains a fairly complete list of other references on the subject of atmometry.)

THE MEASUREMENT OF RAINFALL AND SNOW.

By ROBERT E. HORTON, Consulting Engineer, Albany, N. Y.

[Abstract from Journal of the New England Water Works Association, 1919, vol. 33, no. 1, pp. 14–71, 21 figs., 12 tables.]

SYNOPSIS.—"The object of this paper is to describe methods of measuring rainfall and snow, and to discuss the errors and accuracy of such measurements, with a view to suggesting methods of securing rainfall records having the highest possible degree of accuracy and usefulness. Some attention will be given to the question of the reliability of the results obtained from a single raingage as applied to larger or smaller areas around it."

This thorough paper on the measurement of rainfall and snow opens with a discussion of the history of rain gages and of early observations, particularly those of the United States. Detailed descriptions of various forms of rain gages follow. Passing over many of these details, this review will cover particularly (1) errors of rainfall measurements, (2) suggested methods for the accurate measurement of snowfall, and (3) rainfall on mountain slopes as compared with raingage indications.

"ERRORS OF RAINFALL MEASUREMENTS.

"The usual errors to which rainfall records are subject include:

"1. Observational errors, personal equation, and mistakes.

"2. Instrumental or ratio error.